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H2A
(71, 72 and 74 continued overleaf)

(54) A linear motor

(57) The permanent-magnet armature of a reciprocating linear motor is returned to its starting position by magnetic biasing means when the field coil is deenergized.

One linear motor utilizes the magnetic attraction between a washer or washers (62, 64) formed from a ferrous material, e.g., steel, and a magnetic pole or poles of an armature (26) for automatically returning the armature to its original position (as shown in Fig. 1) upon the deenergization of a field coil (54 or 56). Each washer (62 or 64) is located in alignment with and in surrounding relation to one of the effective poles (40 or 44) of the armature (26) when the field coil is not energized. The stroke of the armature (26) is limited to a distance (Y) which ensures that at the end of the stroke the one effective pole (40 or 44) will be located closer to its respective washer (62 or 64) than any other effective pole (44, 70 or 40).

Another linear motor, Fig. 12, 13 (not shown), uses a fixed bias magnet and the field coil affects the balance between forces on the armature due to a coiled spring on one side and to the magnetic repulsion, between like poles of the fixed magnet and the armature magnet, on the other side.

Either of these linear motors, in their various embodiments, may be incorporated into a shutter control mechanism for a photographic camera, Figs. 7, 8 (not shown), wherein the motor armature is connected to an electromagnet (74'), the motor and electromagnet being energised together periodically to grip and advance stepwise a rod (78') so that shutter blades (212, 214) are stepped open until the proper exposure is reached.

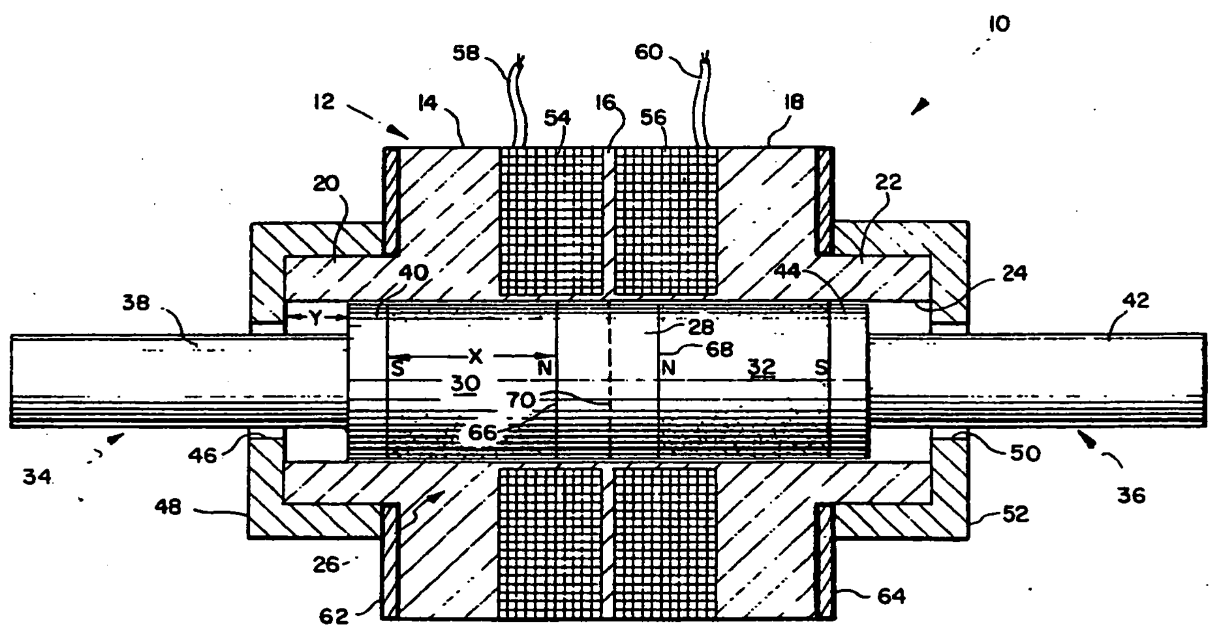

FIG. I

GB 2 052 886 A

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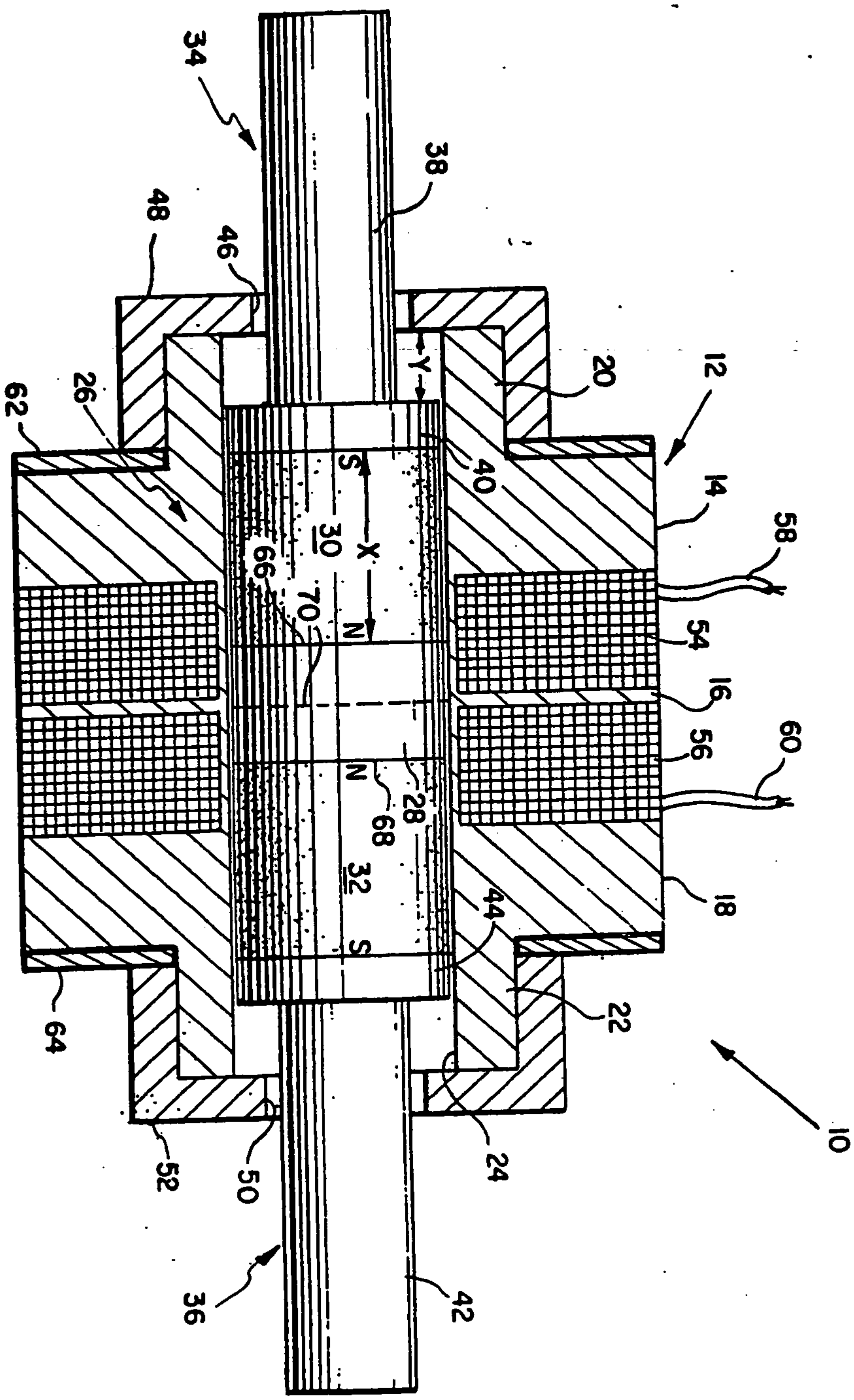

10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
X
Y
S
N
N
S

FIG. 1

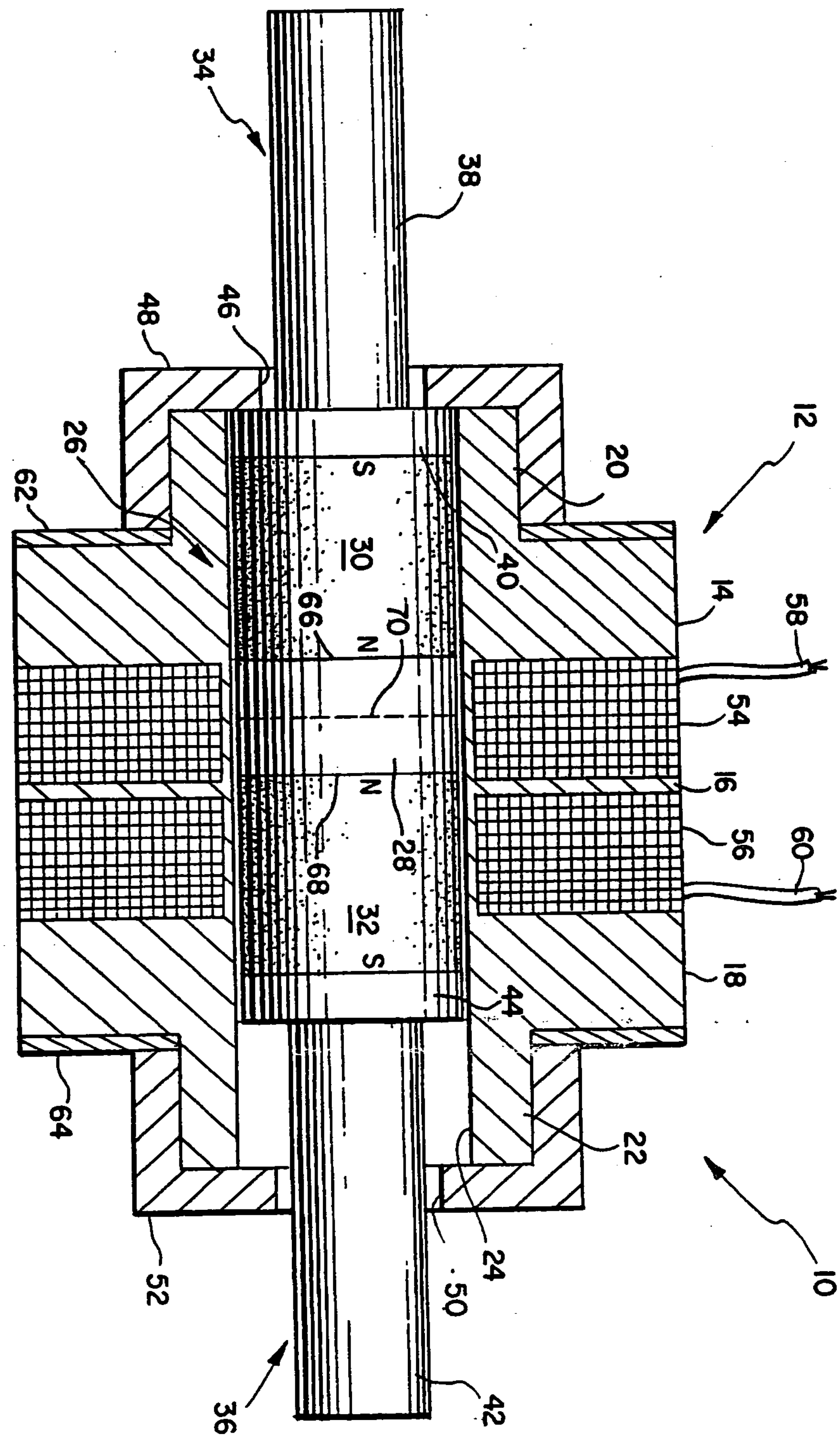

34
38
48
46
26
62
12
20
40
30
S
66
70
N
14
58
54
N
16
28
68
56
60
32
S
18
44
22
64
52
24
50
10
36
42

FIG. 2

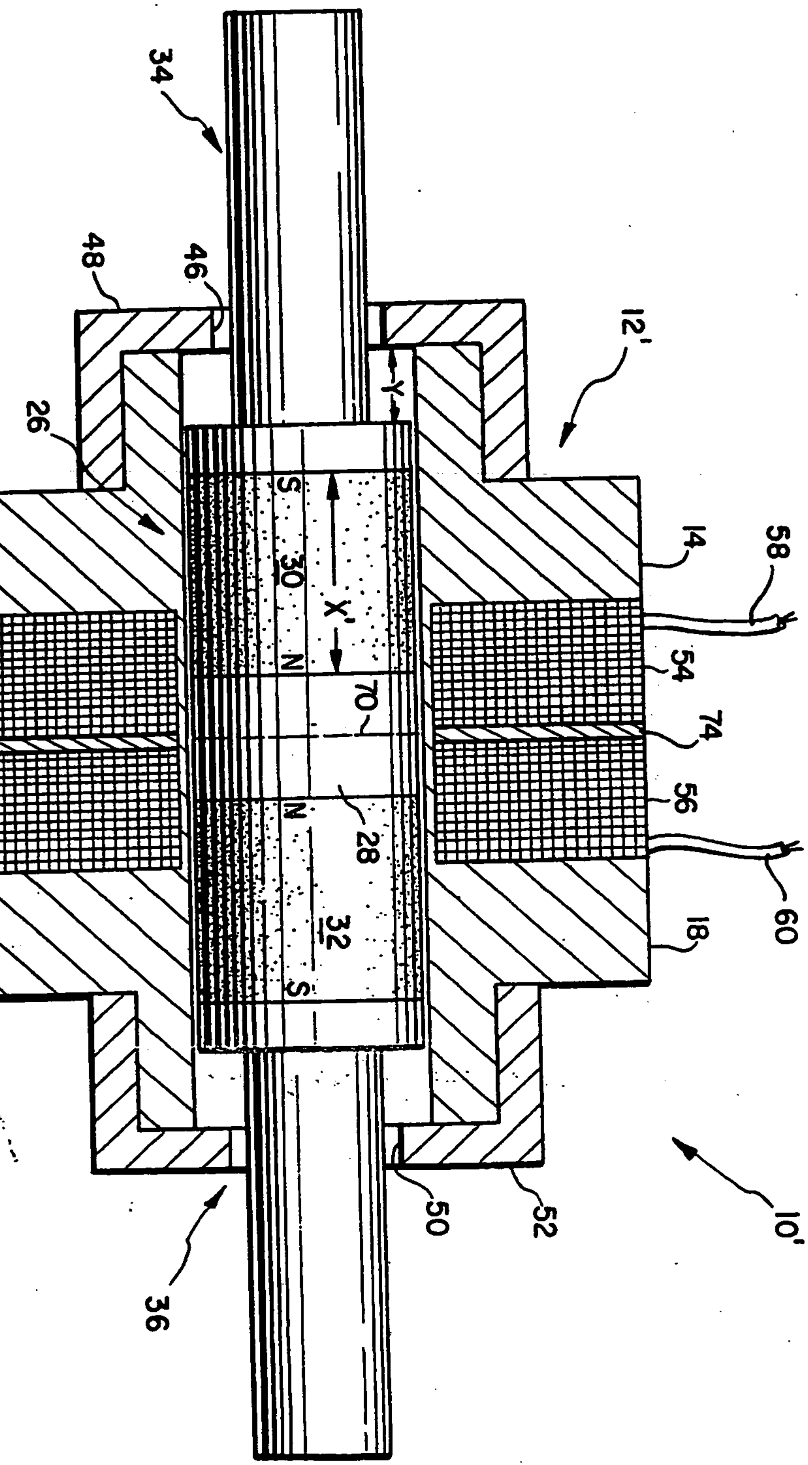


FIG. 3

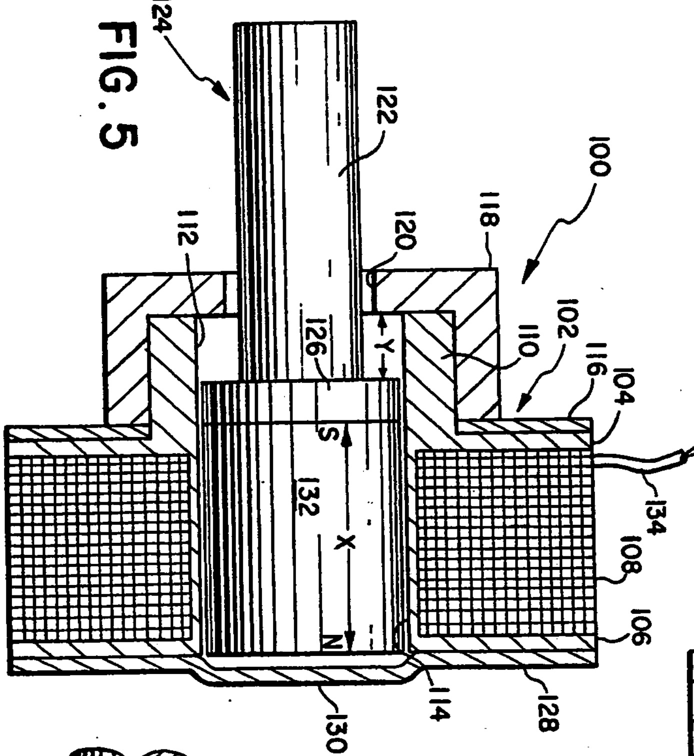


FIG. 5

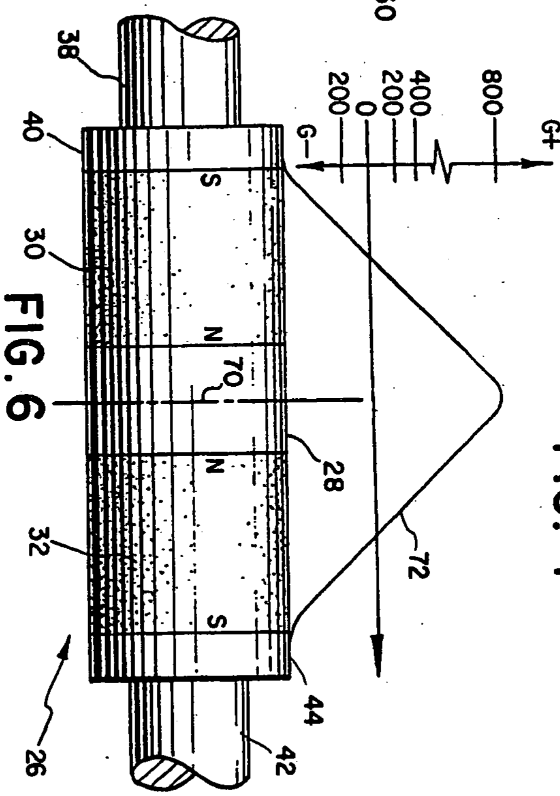


FIG. 6

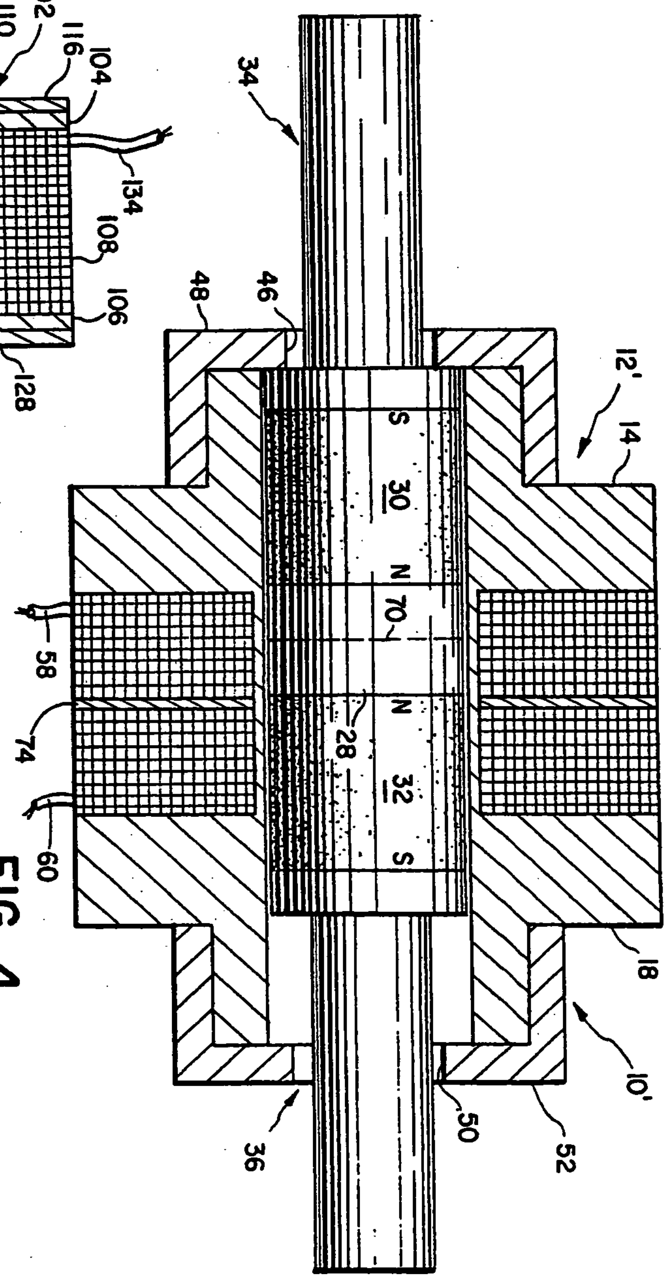


FIG. 4

Fig. 7.

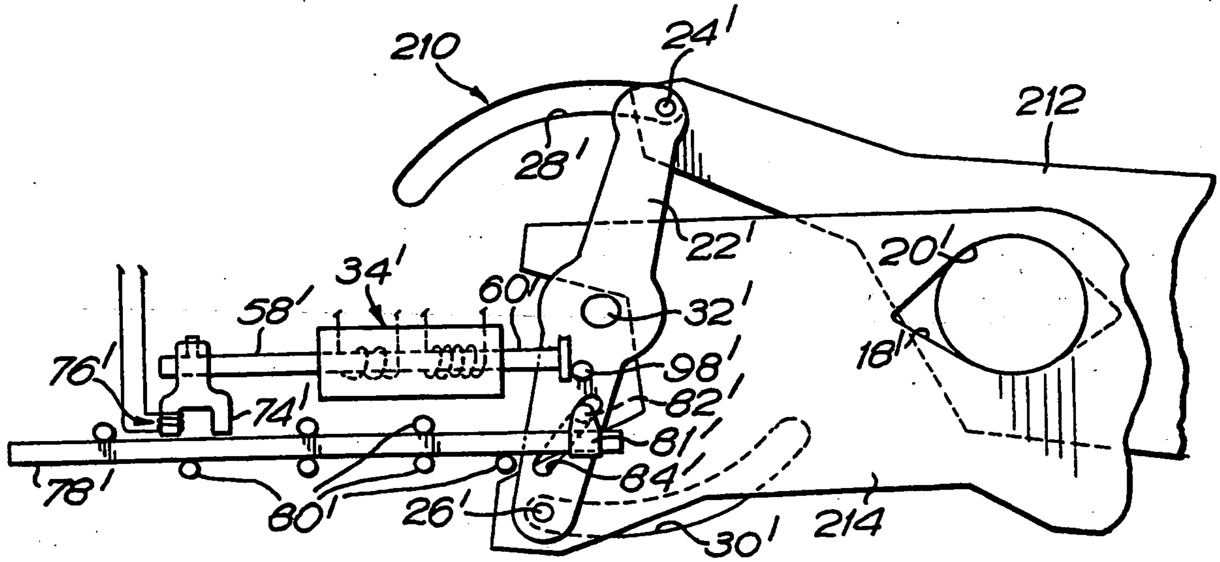

210
24'
212
28'
22'
20'
34'
60'
58'
32'
18'
76'
98'
82'
74'
81'
84'
78'
80'
26'
214
30'

Fig. 8.

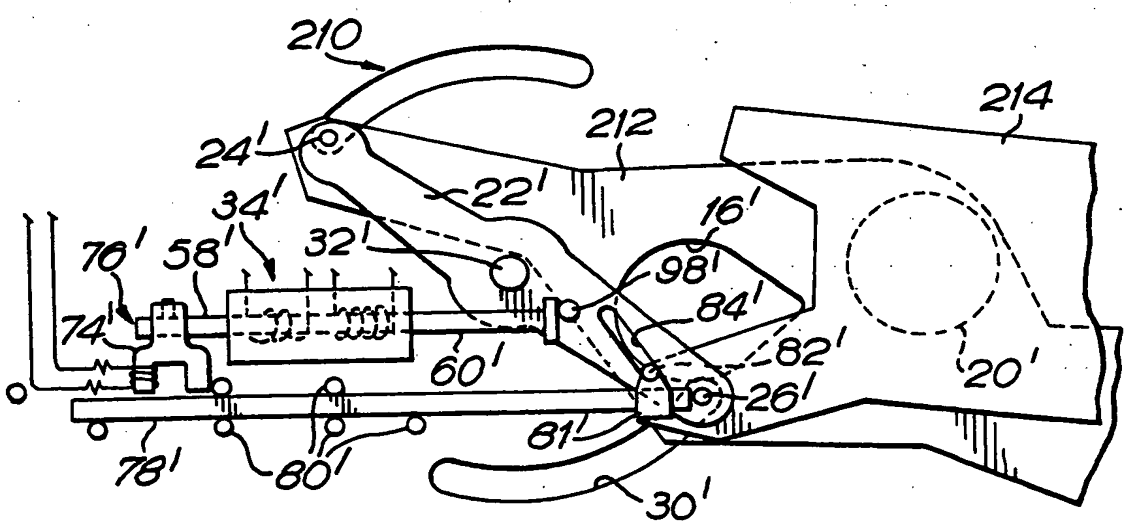

210
214
212
24'
22'
34'
16'
76'
58'
32'
98'
74'
84'
60'
82'
20'
26'
81'
78'
80'
30'

Fig. 9.

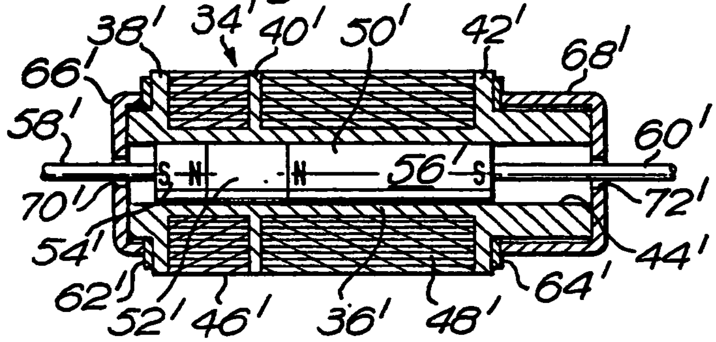

38'
34'
40'
50'
42'
68'
66'
58'
60'
S
N
N
56'
S
70'
72'
54'
44'
62'
64'
52'
46'
36'
48'

Fig. 10.

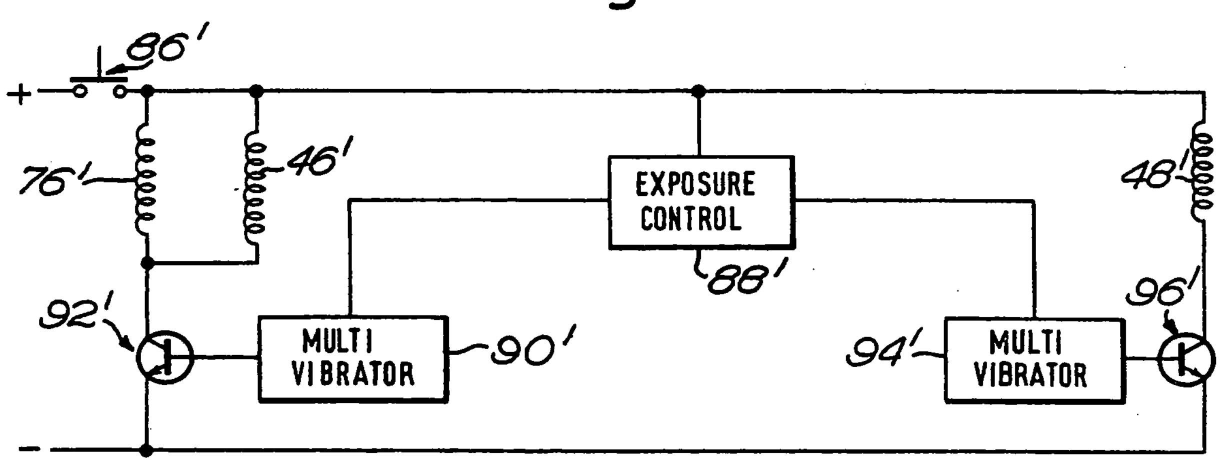

86'
+
76'
46'
EXPOSURE
CONTROL
48'
88'
92'
96'
MULTI
VIBRATOR
90'
94'
MULTI
VIBRATOR
−

Fig. 11.

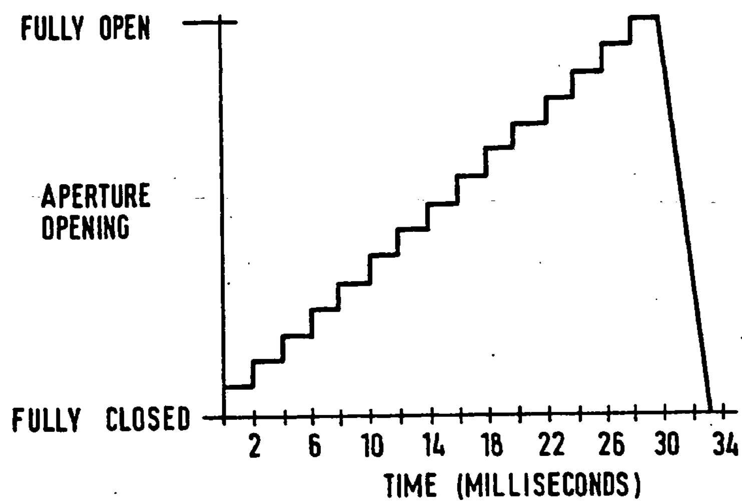

FULLY OPEN
APERTURE OPENING
FULLY CLOSED
2
6
10
14
18
22
26
30
34
TIME (MILLISECONDS)

Fig. 14.

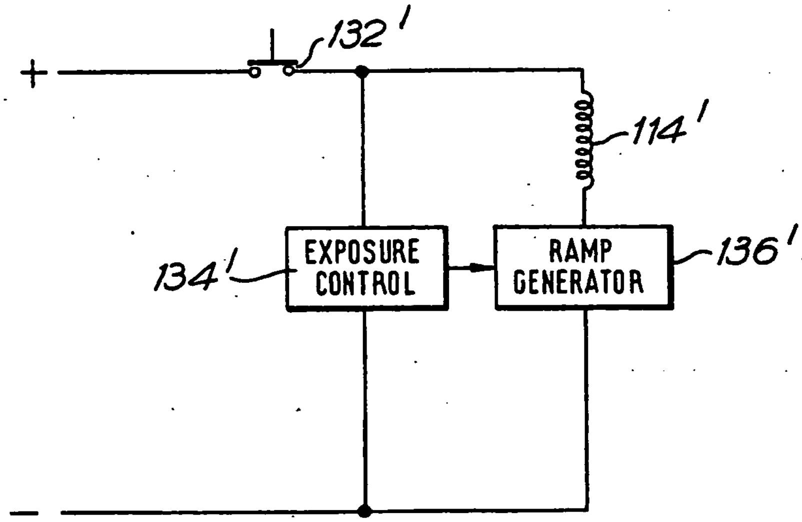

+
132'
114'
134'
EXPOSURE CONTROL
RAMP GENERATOR
136'
−

Fig. 12.

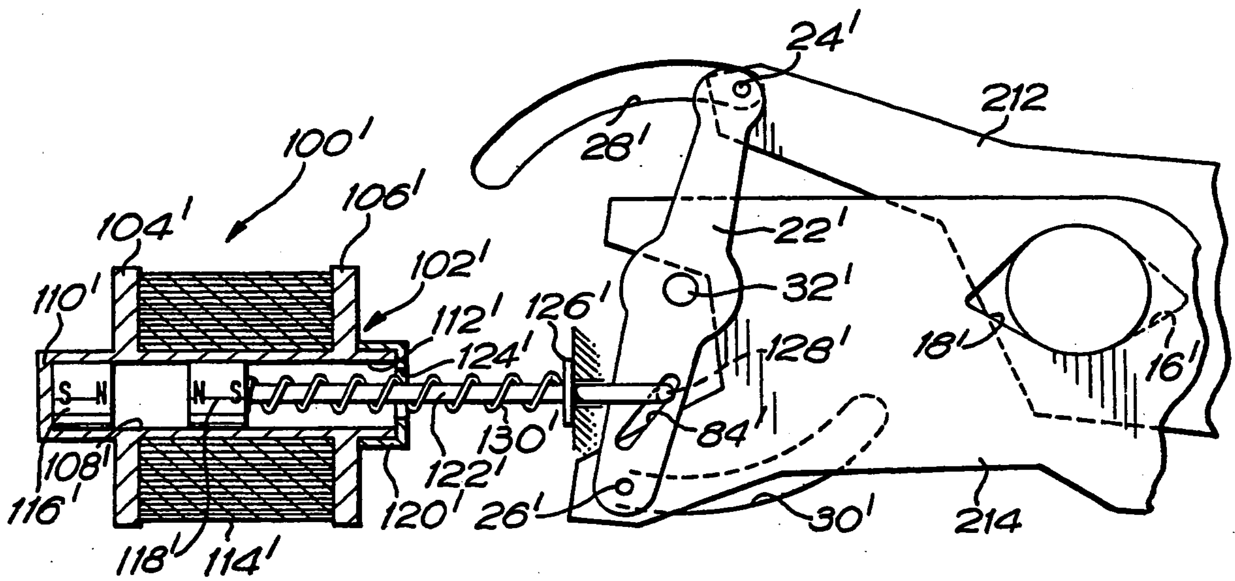
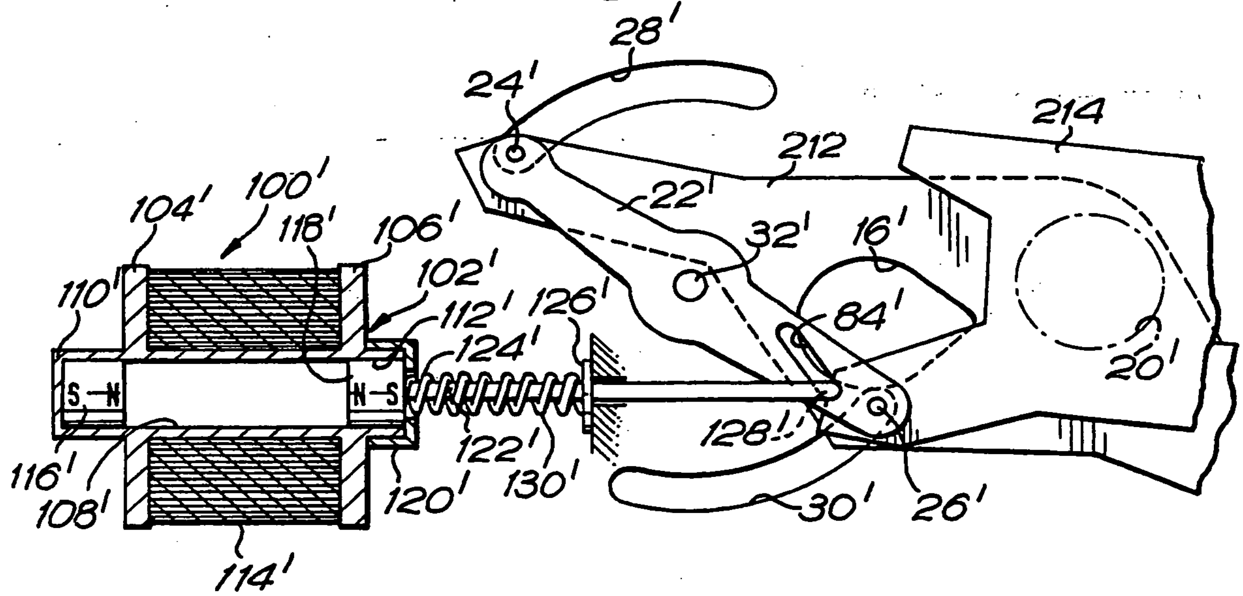

24'
212
28'
100'
106'
104'
22'
102'
32'
110'
112'
126'
124'
128'
18'
16'
S N
N S
84'
130'
108'
122'
116'
120'
26'
30'
214
118'
114'

Fig. 13.


28'
24'
214
212
100'
22'
104'
118'
106'
32'
16'
102'
110'
84'
112'
126'
124'
20'
S N
N S
122'
128'
116'
130'
120'
30'
26'
108'
114'

SPECIFICATION

A linear mot r

This invention relates to a linear motor and to positioning apparatus and photographic apparatus incorporating a linear motor.

Dynamoelectric motors are well known and generally include a bobbin about which is wound one or more field coils. Mounted within the bobbin is an armature which may b comprised of a core formed from a piece of s ft iron, as shown in U.S. Patent No. 3728654; or it may be comprised of a plurality of permanent magnets, as shown in U.S. Patents Nos. 3022400, 3202886 and 3495147; or the armature may be a combination of a core and a permanent magnet. The application of a direct current in one direction to the field coil generates a magnetic field which produces a force to drive the armature in a first direction until it is physically stopped and the reverse application of the direct current to the field coil will cause the armature to be driven in an opposite direction until it again hits a physical stop. One disadvantage of the motors described and shown in the above-identified patents is that each output shaft produces only one stroke for each energization and deenergization of its field coil. In other words, the armature does not return to its original position upon the deenergization of its field coil.

One of the problems with returning an armature to its original position is the precise positioning of the armature relative to the field coil thereby insuring that the length of each stroke is substantially the same. One proposed solution is offered in U.S. Patent No. 3,549,917 wherein opposing springs are used to center or return an armature to its original position upon the deenergization of its fi ld coil. Also, see U.S. Patent No. 3,755,699 wherein flexible diaphragms are used to return a bobbin to its central position. However, the matching of the opposing springs or diaphragms to insure that they will always provide equal and opposite forces leaves much to be desired, both practically and economically.

U.S. Patent No. 3,860,300 describes a control system including a plurality of permanent magnets made from samarium cobalt and a pair of electromagnets for repositioning a rotating shaft. The output of each electromagnet is controlled by a circuit containing a differential amplifier. See also U.S. Patent No. 3,874,750 wherein a permanent magnet thrust bearing system is used to locate a rotatable shaft relative to a fixed number. However, neither of these systems is related to an environment wherein a field coil is energized to move an armature axially in order to provide an output for driving a member; and, when deenergized is automatically returned to its original position.

An object of the invention is to provide a linear motor with improved means for r turning an armature to its original position upon deenergizing a field coil.

In the photographic art, shutter mechanisms, such as that shown in U.S. Patent No. 3,533,346, are designed to utilize the advantageous characteristics of springs to derive the opening movement of the shutter blades. Such springs provide both desirable consistency of dynamic performance as well as relatively high available energy. To operate the shutters, power is required and, in most applications that power is delivered to the springs by an energy storing cocking procedure through a solenoid actuated ratchet assembly, as in the above-mentioned patent, or through a hand-driven device such as a film advance lever.

With the advent of the miniature but fully automated camera, a need was developed for a correspondingly compact shutter assembly which would remain accurate while operating under relatively low power levels, i.e., the compactness of the shutter assembly foreclosed the use of relatively large, strong springs for driving the shutter blades. Such an assembly is shown in U.S. Patent No. 3,882,522 wherein a stepper motor is used to sequentially move the shutter blades toward a fully open orientation and then the motor is energized in an opposite directional sense to reverse the direction of movement of the shutter blades and return them in steps to a closed orientation. By so stepping the blades into the open position, mass-accelerative forces are materially reduced thereby minimizing any overshoot at the time that the direction of movement of the blades is reversed.

An auxiliary object of the invention is to provide photographic apparatus for sequentially opening the blades of a shutter and for rapidly returning the blades to a closed orientation.

A linear motor according to the invention comprises: electrically conductive means wound upon a supporting means, the supporting means including means defining a passageway extending axially of the supporting means; an armature mounted within the passageway for axial movement relative to the supporting means between first and second positions, the armature including a permanent magnet whose poles are orientated along the passageway, the electrically conductive means wound upon the supporting means moving the armature from its first position to its second position upon being electrically energized; means mounted on one end of the armature for transmitting the movement of the armature to an apparatus to be driv n thereby; means for limiting the extent of the movement of the armature along the passa-

geway upon energization of the electrically conductive means; and means mounted on the said supporting means and magnetically cooperating with one of the effective poles of the said armature when the armature is in its second position for returning the armature to its first position upon deenergization of the electrically conductive means.

In a first embodiment, the means which magnetically cooperates with the permanent magnet in the armature is formed from a ferrous material and comprises an annular disc through whose armature passes a portion of the armature, the disc mounted substantially in alignment with the said effective pole of the armature when the armature is in its first position.

In a second embodiment, the said means mounted on the said supporting means compris s a second permanent magnet fixedly mounted within the said passageway with its magnetic poles orientated along the passageway, such that common poles of the said first and second permanent magnets face each other and create a magnetic field having a force sufficient to return the armature into its first position on deenergization of the electrically conductive means, and the linear motor further comprises means for resiliently biasing the armature towards its second position, the biasing means having a force less than that created by the said magnetic field, but such that on energizing the electrically conductive means in a manner so as to create a magnetic field in opposition to the magnetic field naturally occurring between the said first and second permanent magnets to reduce its force to a level below that of the said biasing means, the said biasing means moves the armature in its second direction.

Photographic apparatus incorporating the second embodiment of the invention, for controlling the movement of shutter blades during an exposure interval, also comprises a photographic shutter including a pair of blades mounted for movement between a closed orientation and an open orientation in which scene light may pass to a focal plane as the blades are moved between their closed and open orientations; means for connecting the said blades for simultaneous movement, coupled to the said means mounted on one end of the armature for transmitting the movement of the armature to the said blades; and means for energizing the electrically conductive means so that the said biasing means moves the armature in its second direction to thereby move th said blades from their closed orientation toward th ir open orientation, wherein the armature is returned to its first position and the blad s to their closed orientation on deenergizing the electrically conductiv means.

A positioning device incorporating the first embodiment of the invention, wherein th armature has first and second output members for transmitting the movement of the armature to apparatus driven by the motor, additionally comprises an electromagnet fixedly secured to the first output member; a link coupled to a positionable member; means for mounting the link for movement in first and second directions of motion of the armature, the said mounting means maintaining the said link adjacent to the said electromagnet as the link is moved in the first and second directions; and means either for simultaneously energizing the winding of the said electromagnet and the said electrically conductive means to thereby magnetize the electromagnet and magnetically draw the link in the first direction as the armature is moved in the first direction or, alternatively, for energizing the electrically conductive means so as to move the armature in the second direction so as to move the second output member into engagement with the positionable member. Preferably, the electrically conductive means includes first and second coils selectively energizable to move said armature in said first and second direction, respectively, and the distance travelled by the armature under the influence of the force created by energizing the second coil is substantially greater than the distance travelled by the armature in its first direction under the influence of the force created by energizing the first coil.

Photographic apparatus incorporating the positioning device described above, for controlling the movement of shutter blades during an exposure interval, also comprises: a photographic shutter including a pair of blades mounted for movement between a closed orientation and an open orientation in which scene light may pass to a focal plane; means for connecting the said blades for simultaneous movement between their said closed and opên orientations, wherein the said positionable member is coupled to connecting means for incrementally moving the blades from the closed orientation towards their open orientation when the said link moves in the first direction, and for rapidly returning the blades to their closed orientation when the said armature is moved in the second direction; and means for generating a sequence of electrical pulses to energize the linear motor in its first direction to displace the blades from their closed orientation and for generating an electrical pulse to energize the linear motor in the opposite direction rapidly to return the blades to their closed orientation thereby terminating the exposure interval.

For a fuller understanding of the inventi n, ref rence should be had to the following detailed description of sev ral embodiments of th invention taken in c nnection with the accompanying drawings wherein:

Figure 1 is an enlarg d elevated view, partly in cross-section, of a preferred embodi-

ment of a linear motor in a non-energized condition;

Figure 2 is a view of the linear motor of Fig. 1 showing the position of its armature when one of its field coils is energized;

Figure 3 is an enlarged elevational view, partly in cross-section, of an alternative embodiment of a linear motor, shown in its non-energized condition;

Figure 4 is an elevational view of the linear motor of Fig. 3 in an energized condition;

Figure 5 is an enlarged elevational view, partly in cross-section of another embodiment of the instant invention;

Figure 6 is a diagrammatic showing of the r lationship between an armature of the instant invention and a curve which represents the magnetic flux density of the armature.

Figure 7 is an elevational view of a photographic shutter system incorporating a positioning device comprising a linear motor according to the invention, the shutter blades being shown in a fully opened orientation;

Figure 8 is a view similar to Fig. 7, showing the shutter blades in a closed orientation and motor energized for closing;

Figure 9 is an enlarged elevational view of a linear motor used in the system shown in Figs. 7 and 8;

Figure 10 is a schematic circuit diagram for the system shown in Figs. 7 and 8;

Figure 11 is a graph representing the relationship between the aperture opening and time for the shutter system shown in Figs. 7–10;

Figure 12 is an elevational view of an alternative embodiment of a photographic shutter system incorporating a linear motor according to the invention, the blades of the shutter being in a fully open orientation;

Figure 13 is a view similar to Fig. 12, showing the shutter blades in a closed orientation; and

Figure 14 is a schematic circuit diagram for the system shown in Figs. 12 and 13.

Reference is now made to Figs. 1 and 2 of the drawings wherein is shown a preferred embodiment of a linear motor 10, the motor's exterior housing being omitted for reasons of clarity. The motor 10 includes a generally cylindrically shaped bobbin 12, which is preferably of a nonconducting material such as Delrin, a thermoplastic resin sold by E. I. duPont de Nemours & Co. The bobbin 12 includes a plurality of annular cheeks 14, 16 and 18, end sections 20 and 22, and a longitudinally extending cylindrical passageway 24.

Mounted within the passageway 24 for reciprocating movement is an armatur 26. The armature 26 includes a core 28, preferably formed from steel, and two permanent magnets 30 and 32, preferably formed from a rare earth material such as samarium cobalt. Each f the magnets 30 and 32 has a common pole such as its north poie N fixedly s cured to an end face of the steel core 28 such that the south poles S of the magnets define the opposite ends of the armature 26.

A pair of output rods 34 and 36, preferably formed from Delrin, ar fixedly secured to opposite ends of the armature 26. The output rod 34 includes an elongate cylindrical arm 38 and a head portion 40 of a diameter greater than that of the arm 38. The output rod 36 includes a similar arm and head portion 42 and 44, respectively. The arm 38 is adapted to pass through an opening 46 in an end cap 48 while the arm 42 is adapted to pass through an opening 50 in an end cap 52. Each of the end caps 48 and 52 is preferably formed from a thermoplastic material such as Delrin.

A pair of field coils 54 and 56 is mounted in side-by-side relation on the bobbin 12 such that the field coil 54 is located between the cheeks 14 and 16 and the field coil 56 is located between the cheeks 16 and 18. Each of the coils 54 and 56 is provided with an electrical cord 58 and 60, respectively, for connecting its associated field coil to a source of direct current. Each of the cords includes a pair of wires for completing a circuit through the coil.

A pair of washers 62 and 64, preferably formed from a magnetically permeable material such as soft steel, is provided for automatically moving the armature 26 from the position shown in Fig. 2 to the position shown in Fig. 1 upon deenergizing the field coil 54. The washer 62 is mounted on the end section 20 so as to encompass and be in alignment with the left effective south pole of the armature 26 and is secured thereon by the end cap 48. The washer 64 is similarly mounted on the end section 22 so as to encompass and be in alignment with the right effective south pole of the armature and is secured thereon by the end cap 52.

As mentioned hereinabove, the north poles of the magnets 30 and 32 are fixedly secured to the axial end faces 66 and 68 of the steel core 28 in order to provide a zone of maximum magnetic flux density which extends radially outwardly from the central portion of the steel core 28 thereby creating an armature which in effect has three poles, i.e., two south poles designated S in the drawings and a single north pole designated by the broken line 70. This is graphically illustrated in Fig. 6 by the curve 72 which represents the radial flux density of the armature 26 as measured along its axis. It will be noted that the maximum flux density is in lin with the effective north pole 70 while the flux density of the magnets 30 and 32 reverses at a point equidistant the south and north poles of each magnet.

In one example of a linear motor built according to the instant invention, each of the

magnets 30 and 32 has a length and a diameter of 3.175 mm (.125 inches), the steel core has a length of 1.905 mm (.075 inch) and a diameter of 3.175 mm, the passageway 24 has a diameter of 3.2512 mm (.128 inches) and a length of 12.192 mm (.480 inches), and the bobbin 12 has a maximum diameter of 9.525 mm (.375 inches) and a minimum diameter of 3.5052 mm (.138 inches) at the location where the field coils 54 and 56 are wrapped around the bobbin 12. This combination provides for a maximum gauss of approximately 800 at the effective north pole of the armature 26, as represented by the broken line 70.

In its deenergized state, the armature 26 of the linear motor 10 assumes the position shown in Fig. 1. The armature 26 is moved from the position shown in Fig. 1, hereinafter ref rred to as the first position, to a second position, shown in Fig. 2, by connecting the field coil 54 to a source of direct current. Thus, the armature moves through a distance Y before its left hand effective south pole moves into engagement with the interior surface of the end cap 48. In the example linear motor described above, this distance Y is equal to approximately 1.2065 mm (.0475 inches). So positioned, the effective south pole on the left hand side of the armature 26 is still located closer to the steel washer 62 than the north pole N of the magnet 30. This is always true because the distance Y is less than one-half of X, where X is the distance between adjacent poles of the magnet 30. Accordingly, when the current to the field coil 54 is terminated, the greater magnetic attraction between the effective south pole on the left side of the armature 26 and its associated steel washer 62 provides a force to return the armature 26 to its first position. This force is supplemented by the magnetic attraction that exists between the other effective south pole of the armature 26 and its associated steel washer 64. In the example motor set forth above, each washer preferably has an O.D. of 9.525 mm (.375 inches), an I.D. of 5.08 mm (.200 inches) and a thickness of .254 mm (.010 inch). The magnetic attraction between each washer and its associated effective pole can be increased or decreased by decreasing or increasing, respectively, the diameter of the hole in each washer.

The armature 26 may be moved to the right, i.e., to a third position, by connecting the field coil 56 to a source of direct current. So energized, the head portion 44 of the output rod 36 moves into engagement with the interior surface of th end cap 52 after having traveled through a distance Y. As soon as the field coil 56 is de nergized, the gr ater magnetic force that exists between the ffective south pole of th armature 26 and its associated washer 64, as compared to that which xists between the effective north pole N of the magnet 32 and the washer 64, moves the armature 26 back into its original or first position.

Reference is now made to Figs. 3 and 4 of the drawings wherein is shown an alternative embodiment of a linear motor 10'. The linear motor 10' is substantially identical to the linear motor shown in Figs. 1 and 2 with one major change, i.e., the two steel washers 62 and 64 have been replaced by a single steel washer 74 which is located on the bobbin 12' in the position previously occupied by the cheek 16.

The operation of the linear motor 10' is substantially identical to that of the motor 10 except that in this embodiment it is the greater magnetic force acting between the effective north pole and the single steel washer 74 which moves the armature 26 from either of the second or third positions back into the first position. For example, energization of the field coil 54 by a direct current results in the armature 26 moving to the left, through a distance Y, into the second position wherein the effective south pole on the left of the armature 26 is in engagement with the interior surface of the end cap 48, as shown in Fig. 4. However, the effective north pole 70 is still located closer to the steel washer 74 than either of the effective south poles of the armature because Y is less than one-half of X' where X' is the distance between two effective poles. Accordingly, when the field coil 54 is deenergized, the greater magnetic attraction between the effective north pole 70 and the washer 74 provides the force necessary to return the armature 26 to its centrally located or first position. Energization of the field coil 56 results in the armature 26 moving to the right into its third position.

Reference is now made to Fig. 5 of the drawings wherein is shown still another embodiment of a linear motor 100, the motor being shown in a first or deenergized position. The motor 100 includes a cylindrically shaped bobbin 102 having a pair of annual cheeks 104 and 106 between which is wound a field coil 108. Extending from one side of the cheek 104 is a cylindrically shaped end section 110 having an aperture 112 therein which forms a continuation of a cylindrically shaped passageway 114. A washer 116, made from a magnetically permeable material such as soft steel, is mounted on the end section 110 and retained in place thereon by an end cap 118. The end cap 118 has an aperture 120 for permitting the passage of a portion of a cylindrical shaft portion 122 of an output arm 124. The output arm 124 includes a head 126 having a diameter greater than that of the aperture 120 and slightly less than that of the aperture 112 and the passageway 114. The open end of the passageway 114 is closed off by a plate 128 having a recessed portion 130. The recessed portion

130 is spaced sufficiently from the end of the motor's armature to prevent engagement therebetween when the latter is returned t the position shown in Fig. 5, hereinafter referred to as the first postion. The bobbin 102, the end cap 118, the plate 128 and the output arm 124 are preferably formed from Delrin.

A cylindrically shaped armature 132 is slidably received within the aperture 112 and the passageway 114. The armature 132 consists of a permanent magnet, preferably formed from samarium cobalt, having its eff ctive north (N) and south (S) poles aligned axially of the passageway 114. The effective south pole S of the armature is fixedly secured by any suitable means to the head 126 of the output arm 124. When the armature 132 is in its original or first position, as shown in Fig. 5, the steel washer 116 is located in surrounding relation to and in alignment with the effective south pole S of the armature 132.

The field coil 108 is energized by connecting an electrical cord 134 to a source of direct current. So energized, a magnet field is produced which provides a force for driving the armature 132 to the left (as viewed in Fig. 5) through a distance Y (which is less than one-half of X) where it is stopped in its second position by the interior surface of the end cap 118. When the armature 132 is located in its second position, the effective south pole S is still located closer to the steel washer 116 than is the effective north pole N thereby having a greater magnetic attraction to the washer 116. When the field coil 108 is deenergized, this greater magnetic attraction between the effective south pole S and the washer 116 provides the force for automatically returning the armature 132 to its first position. The recessed portion 130 of the plate 128 allows the armature to momentarily overshoot its first position without causing any potential damage to the armature 132. While the armature 132 has been shown with its effective south pole being aligned with the washer 116 it should be understood that the poles could be reversed, as in all the previous double magnet motors.

Since certain changes may be made in the above apparatus without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense. For example, it is within the scope of the invention to replace the two field coils in the embodiments shown in Figs. 1–4 with a single field coil, and the direction of movement of the armature from the first position to the second position would be in response to the direct current flowing through the field coil in one direction while reversing the flow of direct current would move the armature from the first position to the third position.

Figs. 7 and 8 sh w photographic shutter control apparatus incorporating a positioning device using a linear motor.

The shutter system 210 includes a pair of shutter blades 212 and 214 having tapered apertures 16′ and 18′, respectively, which symmetrically overlap about the center of a stationary aperture 20′ to define a variation of aperture values. The blades 212 and 214 are mounted for movement between a closed orientation, as shown in Fig. 8, and an open orientation, as shown in Fig. 7. For more details on the mounting of the blades 212 and 214, reference may be had to U.S. Patent No. 3,942,183. Each of the blades 212 and 214 is pivotally coupled to a link or walking beam 22′ by a pin 24′ and 26′. The pins 24′ and 26′ are adapted to be located within arcuate slots 28′ and 30′ for guiding the rotation of the walking beam 22′ about its pivot 32′.

A linear motor 34′ is provided for driving the blades 212 and 214 between the closed and open orientations. The linear motor 34′, shown diagrammatically in Figs. 7 and 8 and in cross-section in Fig. 9, includes a cylindrically-shaped bobbin 36′ having spaced cheeks 38′, 40′ and 42′ and a longitudinally extending passageway 44′. A first field coil 46′ is wound upon the bobbin between the cheeks 38′ and 40′ and a second field coil 48′ is similarly mounted on the bobbin 36′ between the cheeks 40′ and 42′.

A longitudinally extending cylindrically shaped armature 50′ is slidably mounted in the passageway 44′ for movement in first (to the left as viewed in Fig. 9) and second directions. The armature 50′ includes a core 52′, preferably formed from steel, and two permanent magnets 54′ and 56′, preferably formed from a rare earth material such as samarium cobalt. Each of the magnets 54′ and 56′ has its magnetic north pole N fixedly secured to an end face of the core 52′ such that the magnetic south poles S of the magnets define the opposite magnetic ends of the armature. A first output member 58′ is fixedly secured to the south pole S of the magnet 54′ while a second output member 60′ is fixedly secured to the corresponding pole of the magnet 56′.

A pair of washers 62′ and 64′, preferably formed from a magnetically permeable material such as soft steel, are mounted on each end of the bobbin 36′ and are secured in place by a pair of end caps 66′ and 68′. The end caps are provided with centrally located apertures 70′ and 72′ for permitting the passage of the first and second output members 58′ and 60′. The bobbin 36′, the end caps 66′ and 68′ and the output members 58′ and 60′ are preferably formed from a nonconducting material such as Delrin.

An electromagnet 74' having a field coil 76' is fixedly secured to the first output member 58'. The coil 76' is located in parallel with the first field coil 46', as shown in Fig. 10, so that it will magnetize the electromagnet 74' every time that the first field coil 46' is connected to a source of direct current.

A rod 78' formed from a magnetically permeable material is slidably mounted underneath the electromagnet 74' by a plurality of pins 80'. The pins 80' provide a frictional force for maintaining the rod 78' in place when the linear motor is not energized. One nd of the rod 78' is coupled to the walking beam 22' by a flange 81' having an inwardly directed pin 82' which rides in a guide slot 84' located in the walking beam 22'.

An exposure interval is initiated by depressing the shutter release button 86' (see Fig. 10) thereby connecting an exposure control 88' with a source of direct current. The exposure control 88' turns on an astable multivibrator 90' which sequentially places a transistor 92' in a conducting and non-conducting condition of approximately two milliseconds each. During each two millisecond period that the transistor is in a conducting condition the coils 46' and 76' are being simultaneously energized. Energizing the coil 46' causes the armature 50' and the electromagnet 74' to move in a first direction until the end of the magnet 54' engages the end cap 66'. Since the electromagnet 74' is magnetized during this movement, it magnetically draws the rod 78' along with it thereby rotating the walking beam 22' in a clockwise manner. When the transistor 92' becomes non-conducting, the armature 50' returns to the position shown in Fig. 9 while the pins 80' frictionally retain the rod 78' in position. When the armature is moved from its first position (shown in Fig. 9) to a second position wherein the magnet 54' is in engagement with the end cap 66', it has traveled through a distance less than one-half the distance between the poles S and N of the permanent magnet 54'. Accordingly, when the armature is in the second position, the south pole S of the magnet 54' is still located closer to the washer 62' than is the north pole N of the magnet 54'. So located, the greater magnetic affinity between the south pole S of the magnet 54' and the washer 62' automatically returns the armature to the first position wherein the south pole S is located substantially in alignment with the washer 62'.

The astable multivibrator 90' continues to turn the transistor 92' off and on thereby sequentially indexing or stepping the shutter blades 212 and 214 toward a fully open orientation such as is shown in Fig. 7. When the exposure control 88' detects that the proper xposure has been obtained, it shuts the astable multivibrator 90' off thereby placing the transistor 92' in a non-conducting state and simultaneously turns on a monostable multivibrator 94' which in turn places a transistor 96' in a conducting state. With the transistor in a conducting state, the second field coil 48' is energized thereby moving the armature 50' in a second direction (to the right as viewed in Fig. 9) until the south pole S of the magnet 56' engages the end cap 68'. This position will hereinafter be referred to as the third position. It will be noted that the distance traveled by the armature 50' in moving from the first position to the third position is substantially greater than that traveled by the armature 50' in moving from the first position to the second position. In one example the former distance was 3.81 mm (.150 inch) as compared to .762 mm (.030 inch) for the latter distance, a magnitude of five. As the armature 50' moves in the second direction, the second output member 60' moves into engagement with a pin 98' extending outwardly from the walking beam 22' and rapidly rotates the latter in a counterclockwise direction into the position shown in Fig. 8, thereby placing the shutter blades 212 and 214 in a closed orientation. As can be seen from the graph in Fig. 11, the time for moving the blades from the full open to full closed orientation is approximately three milliseconds. Once the blades 212 and 214 are fully closed, the exposure control 88' turns the monostable multivibrator 94' off thereby placing the transistor 96' in a non-conducting state and deenergizing the second field coil 48'. With the second field coil 48' in a deenergized state, the armature 50' automatically returns to the first position under the influence of the washer 64'. In other words, the armature 50' automatically returns to the first position because the distance between the first and third positions is slightly less than one-half the distance between the ends of the magnet 56'. Accordingly, when the armature 50' is in the third position, the south pole S of the magnet 56' has a greater affinity for the steel washer 64' than does the north pole N. This greater affinity results in the armature 50' retaining to the first position wherein the south pole S of the magnet is located in substantial alignment with the washer 64', as shown in Fig. 9.

Reference is now made to Figs. 12 and 13 of the drawings wherein is shown an alternative embodiment of the invention. In this embodiment, the shutter blades 212 and 214 are driven between their open and closed orientations by a linear motor 100'. The motor 100' includes a generally cylindrically shaped bobbin 102' having a pair f spaced annular cheeks 104' and 106' and a longitudinally extending cylindrically shaped passageway 108' having a closed end 110' and an open end 112'. Electrically conductiv means in the form of a field c il 114' is wound upon the bobbin 102' in surrounding relation to the passageway 108'. A first permanent magnet

116' is fixedly secured within the closed end 110' of the passageway 108'. The armature of the lin ar motor 100' consists of a second permanent magnet 118'. The poles of the magnets 116' and 118' are rientated such that common poles face each other thereby producing a magnetic field whose force moves the magnet 118' in a first direction until it is stopped by an end cap 120' fixedly secured to the bobbin 102'.

The magnet 118' is secured to an output member 122' which in turn extends through an aperture 124' in the end cap 120' and through an aperture in a fixed bearing plate 126'. An end of the output member 122' is coupled to the walking beam 22' by an inwardly directed pin 128' which rides in the guide slot 84'. The second permanent magnet 118' is mechanically biased in a second direction toward the first permanent magnet 116' by a spring 130' which encircles the output member 122'. The force of the spring is less than that which normally exists between the two magnets 116' and 118'. Accordingly, the second permanent magnet 118' normally occupies the position shown in Fig. 13 wherein it abuts the end cap 120' and maintains the shutter blades 212 and 214 in a fully closed orientation. The output member 122' as well as the bobbin 102' and the end cap 120' are preferably formed from Delrin while the permanent magnets 116' and 118' are preferably formed from a rare earth material such as samarium cobalt.

An exposure interval is commenced by depressing a shutter release button 132' thereby connecting an exposure control 134' to a source of direct current. The exposure control 134' in turn controls a ramp generator 136' which generates a sweep voltage in the field coil 114' which increases linearly in value during one cycle of sweep, then returns to zero suddenly in preparation for another exposure cycle. As the voltage in the coil 114' increases, its magnetic field, which is in opposition to that which normally exists between the two magnets 116' and 118', produces an increasing force which coupled with the force produced by the spring 130' moves the magnet 118' toward the magnet 116'. This movement is transmitted to the walking beam 22' via the output member 122' to rotate the former in a clockwise manner thereby moving the blades 212 and 214 toward their fully open orientation, as shown in Fig. 12. When the correct exposure has been obtained, the exposure control 134' shuts the ramp generator 136' down thereby deenergizing the field coil 114'. With the field coil deenergized, the normal repulsive force existing between the poles of the magnets 116' and 118' rapidly returns the magnet 118' to the position shown in Fig. 13 thereby placing the shutter blades 212 and 214 in a fully closed orientation t end the exposure interval. In one example of a linear motor built according to this embodiment, the magnets 116' and 118' were 2.54 mm (.100 inch) in width and 5.08 mm (.200 inch) in diameter and were spaced 2.54 mm apart when the blades were fully opened, as shown in Fig. 12, and 7.62 mm (.300 inch) when fully closed.

CLAIMS

1. A linear motor comprising: electrically conductive means wound upon a supporting means the supporting means including means defining a passageway extending axially of the supporting means; an armature mounted within the passageway for axial movement relative to the supporting means between first and second positions, the armature including a permanent magnet whose poles are orientated along the passageway, the electrically conductive means wound upon the supporting means moving the armature from its first position to its second position upon being electrically energized; means mounted on one end of the armature for transmitting the movement of the armature to an apparatus to be driven thereby; means for limiting the extent of the movement of the armature along the passageway upon energization of the electrically conductive means; and means mounted on the said supporting means and magnetically cooperating with one of the effective poles of the said armature when the armature is in its second position for returning the armature to its first position upon deenergisation of the electrically conductive means.

2. A linear motor according to claim 1, wherein the means which magnetically cooperates with the permanent magnet in the armature is formed from a ferrous material and is mounted substantially in alignment with the said effective pole of the armature when the armature is in its first position.

3. A linear motor as defined in claim 2, wherein the said means formed from a ferrous material comprises an annular disc through whose aperture passes a portion of the armature.

4. A linear motor as defined in claim 3, wherein the distance travelled by the armature in moving from its first position to its second position is less than one-half the distance between the effective opposite poles of the armature.

5. A linear motor according to any of claims 2 to 4, wherein the supporting means and the limiting means are formed from a non-magnetic material.

6. A linear motor according to any of claims 3 to 5, wherein the armature further includes a second permanent magnet and a core, the core being located between the first-mentioned permanent magnet and the said second permanent magnet with the common poles of the said magnets in engagement with opposite axial end faces of the core thereby

forming an armature having effective common poles at its axial ends and an effective pole of opposite polarity located at a point substantially one-half the distance between the nds of the core.

7. A linear motor according to any of claims 1 to 6, further including second output means mounted on an end of the armature opposite to that at which the first-mentioned output means is mounted, for transmitting the movement of the armature to an apparatus to be driven thereby.

8. A linear motor as defined in claim 6 or claim 7 as appendant to claim 6, wherein the said electrically conductive means is energizabl so as to move the armature from its first position to a third position, the third position being in a direction generally opposite to that tak n by the armature in moving from its first position to its second position.

9. A linear motor as defined in claim 8, wherein the electrically conductive means includes first and second field coils, the first field coil being energizable to move the armature from its first position to its second position and the second field coil being energizable to move the armature from its first position to its third position.

10. A linear motor according to any of claims 6, 8 or 9, wherein the permanent magnets are formed from a rare earth material.

11. A linear motor according to claim 6, 8, 9 or 10, wherein the said one effective pole of the armature is a magnetic pole locat d substantially half way between the opposite ends of the core and the said disc is locat d in alignment with the said one effective pole when the armature is in its first position.

12. A linear motor according to claim 8, 9 or 10, further including a second annular disc formed from a ferrous material through which a portion of the armature passes as the armature moves between its first and third positions, the said discs being mounted on the supporting structure in transverse relation to the armature and substantially in alignment with and in surrounding relation to opposite ends of the armature when the armature is in its first position, the discs cooperating magnetically with the armature to move the armature from its third position to its first position upon deenergization of the electrically conductive means.

13. A linear motor according to claim 1, wh rein the said means mounted on the said supp rting means comprises a second permanent magnet fixedly mounted within the said passageway with its magnetic poles ori ntated along the passageway, such that common pol s of the said first and second p rmanent magnets face each other and create a magnetic fi ld having a force sufficient to return the armature into its first position on deenergization of the electrically conductive means, the linear motor further comprising means for resiliently biasing the armature towards its second position, the biasing means having a force less than that created by the said magnetic field, but such that on energizing the electrically conductive means in a manner so as to create a magnetic field in opposition to the magnetic field naturally occuring between the said first and second permanent magnets to reduce its force to a level below that of the said biasing means, the said biasing means moves the armature in its second direction.

14. A linear motor as defined in claim 13, wherein the said first and second permanent magnets are formed from a rare-earth material.

15. A linear motor as defined in claim 13, wherein the said first and second permanent magnets are formed from samarium cobalt.

16. Photographic apparatus for controlling the opening and closing of a photographic shutter during an exposure interval, comprising: a linear motor according to claim 13, 14 or 15; a photographic shutter including a pair of blades mounted for movement between a closed orientation and an open orientation in which scene light may pass to a focal plane as the blades are moved between their closed and open orientations; means for connecting the said blades for simultaneous movement, coupled to the said means mounted on one end of the armature for transmitting the movement of the armature to the said blades; and means for energizing the electrically conductive means so that the said biasing means moves the armature in its second direction to thereby move the said blades from their closed orientation toward their open orientation, wherein the armature is returned to its first position and the blades to their closed orientation on deenergizing the electrically conductive means.

17. A positioning device comprising: a linear motor according to claim 2, the armature having first and second output members for transmitting the movement of the armature to apparatus driven by the motor; an electromagnet fixedly secured to the first output member; a link coupled to a positionable member; means for mounting the link for movement in first and second directions of motion of the armature, the said mounting means maintaining the said link adjacent to the said electromagnet as the link is moved in the first and second directions; and means either for simultaneously energizing the winding of the said electromagn t and the said electrically conductive means to thereby magnetiz the electromagnet and magnetically draw the link in the first direction as the armature is moved in the first dir ction or, alternatively, f r energizing the electrically conductive means so as to move the armature in the second direction so as to move the second output member into

ngagement with the positionable member.

18. A positioning device as defined in claim 17, wherein the electrically conductive m ans includes first and second coils selectiv ly energizable to move said armature in said first and second directions, respectively.

19. A positioning device according to claim 18, the armature further comprising a second permanent magnet and a core located between the two magnets with common poles of the two magnets engaging opposite axial end faces of the core, the said effective pole and a second effective pole being at opposite nds of the armature, the device further comprising a second ferrous means mounted on the support means in alignment with the said second effective pole of the armature when the armature is in its first position, and wherein the armature is made to return in either the first or the second direction to its first position by the force generated by the magnetic cooperation between the armature and at least one of the ferrous means mounted on the support means, when the lectrically conductive means is deenergized.

20. A positioning device according to claim 19, wherein the said ferrous means and the second ferrous means are annular discs, coaxial with the supporting means, and through whose apertures pass portions of the armature.

21. A positioning device as defined in claim 18, 19 or 20, wherein the force created by energizing the second coil is substantially greater than that created by energizing the first coil.

22. A positioning device according to any of claims 18 to 21, wherein the distance travelled by the armature under the influence of the force created by energizing the second coil is substantially greater than the distance travelled by the armature in its first direction under the influence of the force created by energizing the first coil.

23. Photographic apparatus for controlling the opening and closing of a photographic shutter during an exposure interval comprising: a photographic shutter including a pair of blades mounted for movement between a closed orientation and an open orientation in which scene light may pass to a focal plane; means for connecting the said blades for simultaneous movement between their said closed and open orientations; a positioning device according to claim 22, wherein the said positionable member is coupled to connecting means for incrementally moving the blades from the closed orientation towards their open orientation when the said link moves in the first direction, and for rapidly returning the blades to their closed orientation when the said armatur is moved in the second direction; and means for generating a sequence of electrical pulses to energize the linear mot r in its first direction to displace the blades from their closed orientation towards their open orientation and for generating an electrical pulse to energize the linear motor in the opposite direction rapidly to return the blades to their closed orientation thereby terminating the exposure interval.

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